

INVESTIGATION ON THE INFLUENCE OF SUBSTRATE MATERIALS ON THE TRIBOLOGICAL BEHAVIOUR OF DETONATION GUN SPRAYED ALUMINA COATING

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ABSTRACT

Detonation Gun (D-Gun) Spray Coating is a widely used surface strengthening process applicable for many machine elements and engineering components. D-Gun process gives the unique capability to produce hard surface layers with residual compressive stress, superior adhesive strength and the least porosity in comparison with other thermal spray processes. In addition, flexibility to manufacture the components initially using relatively softer and cheaper materials followed by modification of the functional surfaces using detonation gun spraying of harder materials is a welcome alternative. Experiments were conducted to study the influence of select substrate materials on the behavior of the detonation gun sprayed alumina coatings using optimized process parameters. The experimental investigations relied on the measurement of microhardness, surface roughness, friction and wear behavior as well as by Scanning Electron Microscope (SEM) image analysis of the sprayed alumina coatings on different substrate materials – Stainless Steel SS304, SS316 and Aluminum alloy AA1050. Experimental results suggest that the tribological response of the alumina coated on aluminum alloy in comparison with stainless steels produced durable surface coatings that are superior in resisting environmental degradation.

KEYWORDS: Aluminum, Stainless Steel, Micro Hardness, Alumina, Plasticized, Wear, Interlocking & Bonding

Received: May 15, 2018; **Accepted:** Jun 05, 2018; **Published:** Jul 04, 2018; **Paper Id.:** IJMPERDAUG201825

INTRODUCTION

Engineering components generally fail due to the inability of its functional surfaces to withstand the external forces encountered or to survive the hostile operating environment. The choice of the material is influenced by its physical and chemical properties as well as its resistance to wear, corrosion and functional degradation. Thermal spray is a cost-effective way to protect critical components from wear, corrosion, fatigue, oxidation and high temperature. The advent of newer technologies in surface engineering, notably the thermal spraying processes has presented the designers and the manufacturing engineers with a viable option to appropriately modify the functional surfaces of a component made of low alloy steels or nonferrous material. It is feasible to modify the surfaces of components by appropriate sprayed surface coatings of hard materials to substitute the costly high alloy, bulk steel products that are currently in use to meet the harsh operating environments.

Detonation Gun (D-Gun) Spray Coating is a widely used surface strengthening process applicable for many machine elements and engineering components. D-Gun process gives the unique capability to produce hard surface layers with residual compressive stress, superior adhesive strength and the least porosity in comparison with other thermal spray processes. This approach offers large flexibility to manufacture components initially using relatively softer and cheaper material and then modify the functional surfaces using the detonation gun spraying of harder and degradation resistant materials. It can be used to extend the service life of new parts before they go into operation and to restore worn ones.

The D-Gun coating process is well suited for application in different engineering fields like aviation industry, marine industry, biomedical industry and the defense warfare equipment sector. While conditions in an arid environment can damage military equipment in general, desert wind lifts and spreads fine sand and dust, degrading anything that has moving parts affecting vehicles, sensors, and weapons resulting in accelerated wear and damage. Investigations on D-Gun coating have revealed that alumina (Al_2O_3) deposits are superior considering the weak adhesive strength of other coatings. [1]. Alumina-zirconia ceramic composite has the least sliding wear among the D-gun sprayed alumina-based ceramic composite coatings [2]. In D-gun spraying, higher fuel ratio and lower spray distance result in lower porosity, higher hardness and lower wear loss [3]. The investigation on the variation in the microstructure and phase changes of the sprayed deposits reveals that chemical transformation forming minor phases lead to the strengthening of the deposits and consequently higher hardness [4]. Al_2O_3 layers deposited by detonation gun spraying formed as lamellar structure. The inter-lamellar cohesion and associated voids will dictate soundness of the deposits. The lamellar structure was observed when Al_2O_3 was deposited using d-gun process [5]. Cleaning and grit blasting of substrates make the surface more chemically and physically active paving the way for good bonding. Pre-heating the substrate evaporates the liquid contaminants leading to the deep surface penetration of the sprayed material and better coating adhesion [6]. The adhesion/cohesion of alumina coatings was found to increase with Ra value [7]. The detonation-gun spraying produces the surface coating, which is dense, wear, corrosion and heat resistant, as well as inert to acids, alkali, and solvents, leading to the strengthening of the substrates of ordinary bulk materials [8]. The micro-hardness and the surface roughness of the substrate material influences delamination resistance of the coatings developed on it against impact loads [9]. Substrate material influences the type of splat formation [10]. Changes in the splat morphologies are found when using different substrate materials having different physical and metallurgical properties for developing the surface coating [11].

The metallurgical aspects of the bonding developed in the thermal spray coating/ substrate interface and the behavior of the sprayed particles making up the splats in thermal spray coating process is an area of current research and investigation. However, it is evident that both mechanical interlocking and diffusion bonding come into play in the case of softer and more ductile substrates.

From the literature reviewed, it is found that there is ample scope to investigate the influence of engineering materials, when used as substrates, on the properties of the D-gun sprayed alumina coatings, which is the basis for this study.

MATERIALS AND METHODS

The D-Gun is a water-cooled long barrel closed at one end (Figure 1).



Figure 1: Experimental Set-up for Detonation Gun Spraying Set-Up

The coating powder is injected into the cylinder and a detonation wave is generated by igniting metered quantities of acetylene-oxygen mixture, heating and accelerating the powder into supersonic velocities towards exits, leading to deposition of the coating on the substrate kept at a distance. The cylinder is then purged by a shot of nitrogen. This cycle is repeated three or more times in a second. The performance characteristics of D-gun sprayed coatings are largely influenced by the substrate material in addition to the composition of the combustion gases, the particle size of powder, the pressure of carrier gas, frequency and stand-off distance. In this experimental study, the trials were conducted on stainless steel (or SAE grade 304, 316) and Aluminum alloy AA1050 as typical substrate materials.

Table 1: Chemical Composition (%) of Stainless Steel Grade SS 304

C	Mn	Si	Cr	Ni	P	S	Fe
0.08	2.00	1.00	18.00 20.00	8.00 10.50	0.045	0.03	Bal.

Grade 304 is the most versatile and most widely used stainless steel; Grade 316 is the standard molybdenum-bearing austenitic steel with better corrosion resistance

Table 2: Chemical Composition (%) of Stainless Steel Grade SS 316

C	Mn	Si	Cr	Ni	Mo	P	S	Fe
0.08	2.00	1.00	16.00 18.00	10.00 14.00	2.00 3.00	0.045	0.03	Bal

AA1050 is 99% pure, low strength aluminum possessing excellent corrosion resistance, high ductility and is widely used for general sheet metal work where moderate strength is required. The Chemical composition of the substrate materials is given in Tables 1, 2 and 3.

Table 3: Chemical Composition (%) of Aluminum Alloy AA1050

Fe	Mn	Cu	Zn	V	Si	Cr	Mg	Ti
0.40	0.05	0.05	0.05	0.05	0.25	0.05	0.05	0.03

Cylindrical specimens, Ø8mm X 20 mm long of materials SS304, SS316 and AA 1050 were prepared, grit blasted on one end surface of each specimen and then detonation spray coated with Alumina powder. The process parameters optimized by earlier studies [12] were used for preparing spray coated samples for the experimental study. The experimental setup of d-gun spraying is given in Figure 1. The purity of alumina powder used is 99.97 and the size of the alumina powder is 20 to 30 µm of CUMI make.

The hardness on the alumina coated surface was measured using Vickers Hardness Tester, Model No. DHV3000 (Chroma Systems) at a load of 200gf. The microstructure of the sprayed coatings was examined by using Quanta FEG Scanning Electron Microscope (SEM), Model No. 200. Frictional force and wear of the coating was measured utilizing rotary Tribometer, Model No. TR-201 (DUCOM instruments Pvt. Ltd, India). Wear tests were performed by keeping wear track diameter as 80mm, load as 15N and sliding velocity as 1ms^{-1} on the counter surface of the hardened EN31 disc. Wear loss of each sample was estimated from the weight loss assessed by measuring the weight of samples before and after the pin-on-disc test using a precision balance. Surface roughness was measured using Talysurf TR200 using a cutoff length of 0.25 mm.

RESULTS AND DISCUSSIONS

The SEM micrograph of the deposition of Al_2O_3 (alumina) on Aluminum is shown in Figure 2 which presents mostly plasticized particles with a few molten solidified grains. Discrete voids and microcracks are also seen.

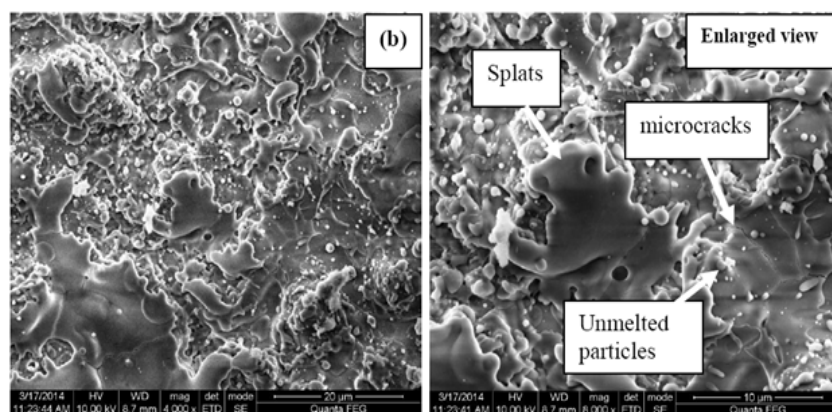


Figure 2: SEM Microstructure of Coated Surfaces of Alumina on Aluminum

Hardness is the most significant property, which influences the service life characteristics of the coatings. From Figure 3, it is seen that the coatings on Aluminium alloy exhibit relatively higher hardness compared to stainless steels (Figure 4 and Figure 5).

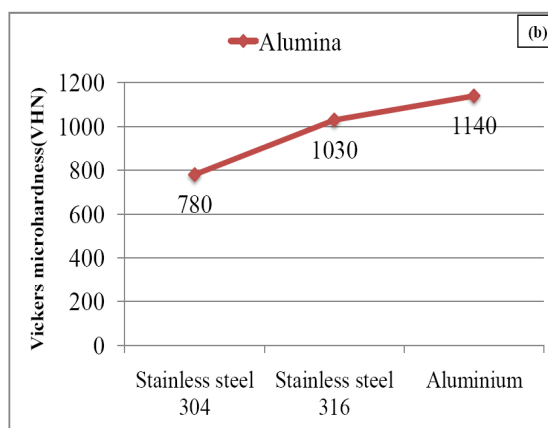


Figure 3: Micro Hardness Variation in Alumina Coatings

The surface area of the substrate is increased by surface preparation like grit blasting leading to increasing in the coating bond strength. Further, the rough surface profile will promote mechanical keying.

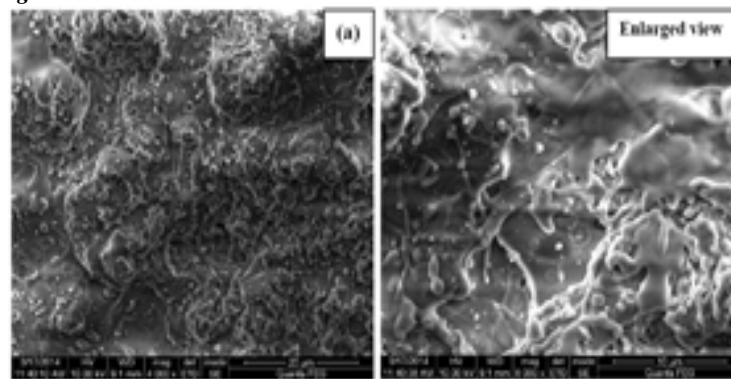


Figure 4: SEM of Alumina Coating on SS 304

The basic mechanism of bonding when the sprayed material is in plasticized or semi-molten state is mechanical interlocking due to the ability of the deposit to reach the grooves and crevices on the component surface.

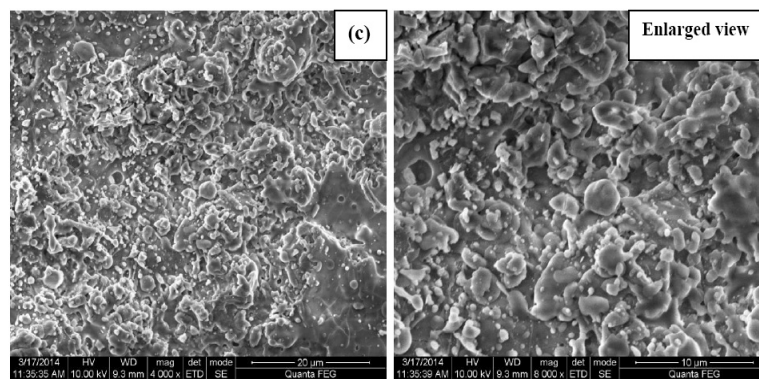


Figure 5: SEM of Alumina Coating (on SS 316)

Table 4: Average Micro-Hardness (VHN)

Substrate Materials	SS 304	SS 316	AA1050
Substrate hardness before coating	455	668	80
Coating hardness after detonation spraying	780	1030	1140

The thermal conductivity of Aluminum alloy is more than 15 times higher than that of stainless steels and hence the layers of splats formed by the sprayed particles tend to solidify faster. Therefore the detonation sprayed alumina particles exist in two phases on Aluminum substrates. The solid-liquid phases present in the sprayed deposit will, in addition to mechanical locking, tend to develop physical diffusion bonding which makes it stronger and harder. The initially deposited splats that instantly solidify keep the top layers of softer Aluminum substrates highly compressed during the repeated impingements during the subsequent detonation spray cycles resulting in high hardness whereas the plasticized/semi-molten particles sprayed on relatively harder stainless steel substrates face resistance to particle diffusion and hence reduced hardness. The measured microhardness values of substrates before alumina coating and that of the deposits after the detonation spraying of alumina are tabulated in Table 4. It is quite evident that the properties of the substrate material influence the quality and nature of layers of splats formed and the quality of thickness buildup.

Table 5: Performance of Sprayed Alumina Coatings on Different Substrates

Substrate	Wear Loss (mm ³)	Friction (N)	Surface Roughness, Ra (μm)	Micro Hardness (VHN)
SS 304	4.32064	8.9	2.089	780
SS 316	1.65792	7.5	1.852	1030
AA 1050	0.90432	6.5	2.072	1140

The sprayed particles that instantly solidify tend to progressively stress and compress the sub-layers at the coating interface of soft and ductile substrates. It is seen from the Table 5 that the wear is the least for the coating of Alumina on aluminum alloy (maximum hardness) and maximum for alumina coated on SS 304 (minimum hardness). The variation of friction force is also found to be proportional to coating hardness. However, variation of the surface roughness of the substrates doesn't indicate any direct relationship.

Obviously, the splats formed on harder substrates like stainless steels do not promote the particle diffusion into substrate layers. The observed decrease in hardness of alumina coated on stainless steels could be due to the fine cracks present in the coating as a result of the induction of compressive residual stress during detonation followed by tensile rarefaction. The wear and friction values also follow similar patterns.

CONCLUSIONS

The following are the significant findings of the experimental study and analysis of the D-gun sprayed alumina coatings on aluminum alloy and the engineering grade stainless steel materials:

- The detonation sprayed particles that instantly cool and solidify tend to compress the top sub-layers of the softer and ductile materials.
- The bonding of splats of sprayed alumina on stainless steel is by mechanical interlocking in the grooves and surface irregularities.
- The bonding of sprayed coating on Aluminum is by mechanical interlocking as well as by physical diffusion bonding resulting in higher hardness.
- It is better to select softer and more ductile material such as Aluminum compared to harder materials such as stainless steels for better functional performance and longevity of components leading to capability enhancement by detonation gun spraying.
- The wear and friction values also corroborate the above conclusion.

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